Fishing profiles of Danish seiners and bottom trawlers in relation to current EU management regulations

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Published in:
Fisheries Management and Ecology

Link to article, DOI:
10.1111/fme.12244

Publication date:
2017

Document Version
Peer reviewed version

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Abstract

Danish seines and bottom trawls operate differently and have different catching processes. Both gears belong to the same legislative category in European fisheries, but different management strategies in other countries and critics by fishers on grouping Danish seines and trawls together indicate disagreement on current gear classification. The present study compared both gears in terms of their fishing characteristics and their catches of commercial species based on 16 years of observer data. Danish seining is a specialized fishing method that targeted few species, but with higher total catch rates than bottom trawlers. Bottom trawling is a more all-purpose fishing method that targets a larger number of species and bottom trawlers use larger engines than Danish seiners. A generalized additive mixed model indicated that catch rates of flatfish are generally higher for Danish seines and catch rates of roundfish species are higher for trawlers. The results do not directly suggest a separation of the gears in terms of legislation as the quantities of fish below current minimum size were similar, but for example future survival studies may reach different conclusions. Additional factors were found to be important in determining catches of both gears.

KEYWORDS

Common Fisheries Policy, demersal fishery, discard ban, generalized additive mixed modelling, landing obligation, observer data

1 INTRODUCTION

Both Danish anchor seines and demersal otter trawls (hereafter referred to as seines and trawls, respectively) are widely-used fishing gears in Denmark (total landings in 2016 by trawlers: 155917 t, by seiners: 6403 t; Ministry of Environment and Food of Denmark, Danish Agrifish Agency) and many other countries. Although different fishing gears are treated separately under European Union (EU) regulations (e.g. beam trawls and otter trawls), seines and trawls belong to the same legislative category (Council Regulation (EC) 850/98). In contrast to the EU regulations, Norwegian regulations distinguish these two gears (Regulations governing the sea-fishing activities J-125-2016; Norwegian Directorate of Fisheries). Owing to the differences between gear designs (e.g. lighter ground gear of seines) and particularly the fishing procedures (Eigaard et al., 2016a; Herrmann, Krag, Feekings & Noack, 2016), this grouping of seines and trawls has been brought into question by fishers and other stakeholders in the EU. Fishers that operate seines claim a loss of more marketable fish than those using trawls when legal mesh sizes are used (see Herrmann et al., 2016). This highlights the need for more detailed information about the two gear types and their catches.

Initially, the seine was developed by a Danish fisherman specifically to catch flatfish, whereas trawls are more opportunistic gears in terms of the species that they target. Today, Norway lobster (a.k.a langoustine) *Nephrops norvegicus* (L.) and several fish species (roundfish and flatfish) are targeted by trawlers. However, a significant proportion of the catches of both gears is discarded (Kelleher, 2005). This happens for several reasons including minimum landing sizes (MLS), quota restrictions and high-grading (Catchpole et al., 2013; Feekings, Bartolino, Madsen & Catchpole, 2012; Kelleher, 2005). In an effort to eliminate discards, a central part of the new Common Fisheries Policy in Europe is a landing obligation, which is being introduced on a fishery-by-fishery basis from 2016 to 2019 (Council Regulations (EU) 1380/2013 and 2016/72). It applies to all species that “define the fisheries”, i.e. species subject to catch limits should be landed. The landing obligation further introduces minimum conservation reference sizes (MCRS, usually equal to current MLS) where fish below this size are not allowed to be sold directly for human consumption (Council Regulation (EU) 1380/2013). The objective of this landing-obligation system is to make fishers be more selective (Condie, Grant & Catchpole, 2013) and to reduce bycatch instead of utilizing quota for less commercial catches (Borges, Cocas & Nielsen, 2016). However, as previous studies found indications of differences in the selectivity characteristics of seines and trawls as well as larger L_{50} values (length at which 50% of the fish are retained) for seines for species like cod *Gadus morhua* L. (Herrmann et al., 2016; Noack, Frandsen, Krag, Mieske & Madsen, 2017), proportions of fish below MCRS are likely different. Furthermore, differences in gear constructions (e.g. lighter ground gears for seiners) might cause differences in the catches of Danish seines and bottom trawls.

The aim of the present study was to use data from a perennial monitoring programme of commercial vessels to establish a comprehensive dataset for describing and comparing the seine and trawl fishery including their catches of commercial species, i.e. quota restricted species and/or species that were directly targeted (for quotas and annual landings in Denmark in 2016, see Table S1). The specific objectives were to: 1) provide an insight into whether the legal grouping of seines and trawls, in terms of catches, is appropriate; 2) assess the two fishing methods in relation to the new management strategies; and 3) identify catch-related problems and challenges with which the fisheries will be confronted under the new landing-obligation system.

2 MATERIALS AND METHODS

2.1 Data collection and selection

Data for the current study originated from a national observer program (1997–2002) and a European discard sampling programme (from 2002) in accordance with the European Data Directive (Council Regulation (EC) 1639/2001). Data were collected during regular fishing trips (i.e. seiners were sampled at daytime, trawlers were sampled at daytime and nighttime) onboard commercial fishing vessels participating in the discard sampling programmes in the period from 1997 to 2012. All fishes were measured for total length (TL), with Norway lobster measured for carapace length, and cephalopods measured for mantle length. In cases where representative sub-samples needed to be taken, individual numbers were raised to haul level following the sampling programme's standard procedure. Fishing practice was assumed to be unaffected by the presence of an observer and the chosen vessels and trips were assumed to be representative for the fishery in the area (Feekings et al., 2012). Further details about the Danish discard sampling programme, including sampling strategy and data collection have been described in Feekings et al. (2012) and in Storr-Paulsen, Birch Håkansson, Egekvist, Degel and Dalskov (2010).

The study area focused on Skagerrak and a small area in northern Kattegat (Fig. 1). Both areas represent a relatively restricted region of large commercial importance where trawlers and seiners fish under similar technical regulations. These regulations have changed several times in the past, including the observed period, though the changes applied to codends in seines as well as in trawls and differences between legislations in Skagerrak and Kattegat were small. Before 1989, 60 mm was the minimum codend mesh size in both areas but increased to 70 mm in 1989 (Kirkegaard, Nielsen & Bagge, 1989), and a mandatory square mesh panel (SMP) was introduced in 2000 (Council Regulation (EC) 850/98). From 2005, the minimum mesh size in codends was 90 mm (diamond mesh) or 70 mm (square mesh codend including a grid), respectively (Council Regulation (EC) 27/2005). Optionally, fishers were encouraged to use a 120 mm SMP, which has been rewarded by extra sea days (Council Regulation (EC) 27/2005). In 2011, the SELTRA panel comprising of either a 270 mm diamond mesh panel or a 180 SMP was made mandatory for codend mesh sizes of 90–119 mm in Kattegat (Vinther & Eero, 2013). In Skagerrak, it was introduced in 2013, but with a 140 mm SMP (BEK No. 1423 of 12/12/2013) instead of 120 mm. Regardless of the changes in technical regulations during the period of the sampling programme, hauls with mesh sizes < 90 mm were excluded to use only comparable mesh sizes in the analyses. Seiners never fished with these small mesh sizes, but trawlers did until the prohibition in 2005. Since codend mesh size was expected to influence catches, the dataset was divided into two equalized categories (90–109 mm and ≥ 110 mm). Regulations and technical measures for towed gears did not only prescribe specific mesh sizes, but also additional selectivity devices like escape windows (Council

Regulation (EC) 850/98). As the specification of these devices was not sufficiently documented in the dataset, the effects of device specification have not been taken into account in the analyses.

2.2 Description and comparison of fishing characteristics and catches

The first part of the analysis was a general comparison of both fisheries including observation information (years of observation, number of observed vessels and number of observed hauls), characteristics of the fisheries (engine power, haul duration, fishing depth and target species) and general catch information (catch per haul, catch per hour). Where appropriate, values were calculated as mean values ± SD and a two-way analysis of variance (ANOVA) with gear and mesh size as fixed factors followed by a Tukey-HSD test was used to test for significant differences between categories (significance level $\alpha \leq 0.05$).

This looked, at the species level, into the catches of commercial species i.e. species with quota in 2016 and/or explicitly targeted by the vessels considered within the dataset. After providing general information about the potential existence of quota in 2016 and potential minimum size (MS as either MLS or MCRS), information is provided about occurrence (observation frequency as number of hauls with observation divided by the number of hauls in total) and total number of caught individuals.

In addition, catch rates (number per hour) were calculated and a MS ratio (number of individuals below current MLS or potentially coming MCRS/total number of individuals per haul) was estimated for all species that have a MS. Both measures were calculated as mean values ± SD. Testing for significant differences between the categories was done using a two-way analysis of variance (ANOVA) with gear and mesh size as fixed factors followed by a Tukey-HSD test (significance level $\alpha \leq 0.05$). This approach detected several significant differences between gear and mesh size categories, but R^2 values were very low (Table S2, Table S3), which indicated a high unexplained deviance. To account for this and to find out which other factors than gear type and mesh size determined catch rates and MS ratios of the different species, both measurements were investigated in more detail. Models were formulated that included all additional parameters that were available from the dataset, that might be of relevance in determining catch rates and MS ratios and that could affect catches of seiners and trawlers differently, i.e. depth, haul duration, latitude, longitude, subsampling factor, target species, trip number, vessel name, engine power, year and year quarter. Four of them (haul duration, longitude, engine power, year) had to be excluded due to collinearity with other covariates (variance inflation factors > 3; Zuur, Ieno & Elphick, 2010).

Generalized additive mixed models (GAMMs) were used to describe relationships between catch rates or MS ratios and the explanatory variables to account for the unbalanced sampling design between explanatory variables (e.g. different number of hauls for different gear categories). For the catch rate models, a Poisson distribution was assumed because catch rate represents count data, i.e. number of fish per unit of effort. Cases of over-dispersion (conditional variance exceeds the conditional mean and/or presence of many zero observations) were handled using a negative binomial distribution (Zuur, Ieno, Walker, Saveliev & Smith, 2009). Both distributions were applied, using a log-link function. Zero-observations were included into the analysis because they form an important part of the total observations. Conditions on different vessels may have differed due to vessel type, vessel size, skipper effects or vessel-specific sorting behaviors (Feekings, Lewy & Madsen, 2013; Poos & Rijnsdorp, 2007; Tschernij & Holst, 1999), but the data structure could be regarded as a hierarchical structure, i.e. vessel – trip – haul. Therefore, vessel and trip were always included in the model, even if the model found them to be non-significant. Furthermore, the subsampling factor was included as an offset in all models as the ratio of individuals observed and individuals measured. It was the only variable which was transformed (log-transformation).

The following was the GAMM for catch rates per haul i (Eq. 2):

$$\begin{aligned}&\text{Catch rate}_i \sim \text{Poisson / negative binomial}(\mu_i, \sigma)\text{, where}\\ &\quad \log(\mu_i) = \eta + \beta(\text{gear}_i) + \gamma(\text{mesh}_i) + \delta(\text{quarter}_i) + \zeta(\text{target}_i) + s(\text{depth}_i) + \\ &\quad s(\text{latitude}_i) + \text{random effect (vessel}_i) + \text{random effect (trip}_i) + \\ &\quad \text{offset (log(subsampling factor}_i)) + \varepsilon\end{aligned} \tag{1}$$

Fixed effects are the nominal covariate “gear” representing either trawl or seine, the continuous covariate “mesh” for the used numerical mesh size, the nominal covariate “quarter” for the quarters of a year, the nominal covariate “target” for the targeted species and the continuous covariates “depth” and “latitude” representing the fishing depth and the respective north-south position. “Vessel” and “trip” as nominal covariates are random effects that represent the respective fishing vessel and trip number. η describes the intercept, which represents seines that fished in quarter one and targeted cod, s is an isotropic smoothing function that was used to define smooth terms (thin-plate regression spline; Wood, 2003), and ε is an error term.

For MS ratios, the procedures explained for the catch rate models were followed, but since ratios can take values between 0 and 1, a binomial distribution was used. Cases of over-dispersion were handled by using a quasi-binomial distribution. For both distributions, a logit-link function was applied.

The GAMM for MS ratios per haul i (Eq. 2) was:

$$\begin{aligned} MS\ ratio_i &\sim \text{binomial / quasibinomial } (\mu_i, \sigma), \text{ where} \\ &\text{logit}\left(\frac{\mu_i}{1-\mu_i}\right) = \eta + \beta(\text{gear}_i) + \gamma(\text{mesh}_i) + \delta(\text{quarter}_i) + \zeta(\text{target}_i) + \\ &s(\text{depth}_i) + s(\text{latitude}_i) + \text{random effect (vessel}_i) + \text{random effect (trip}_i) + \\ &\text{offset (log(subsampling factor}_i)) + \varepsilon \end{aligned} \tag{2}$$

The following steps of model selection and model validation were the same for both models. After estimating the model, the least significant covariate with largest P-value was removed and the new model was applied again. If there were non-significant results in the categorical terms (quarter, target), then levels were combined and the model was refitted. This was done until all remaining covariates except vessel and trip were statistically significant ($P < 0.05$). The final model was validated by checking residuals for linearity and normality (scatterplot of residuals vs. fitted values and histogram), spatial independence (scatter plot of residuals vs. position as spatial factor) and still existing patterns in relation to covariates (scatter plot of residuals vs. remaining covariates). Outliers were identified in the original data and further examined, but no observations were removed since no oddities were found. Results are shown for all models, which passed all steps of the validation process.

All analyses were done in R Statistical Software (R Core Team, 2015), using the package "mgcv" (Wood, 2011) to conduct generalized additive mixed modelling.

3 RESULTS

3.1 Fishing characteristics

The dataset consisted of 285 and 460 fully-commercial hauls for seines and trawls, respectively (Table 1, Fig. 1). In relative terms, more hauls by seiners were conducted using large mesh sizes, whereas trawlers used more often smaller mesh sizes (Table 1). Mean engine power was significantly lower for seiners than for trawlers for both mesh size categories (Table 1) and mean haul duration for seiners was less than half compared to trawlers (Table 1). Areas fished by trawlers and seiners overlapped in some cases (Fig. 1), but mean fishing depth for seiners using mesh sizes ≥ 110 mm ("a" in Table 1) was significantly lower than for the other categories (Table 1). Mean fishing depth for seiners 90–109 mm ("b" in Table 1) and trawlers 90–109 mm ("c" in Table 1) were also significantly different, but both were not significantly different to the values for trawlers using a mesh size ≥ 110 mm ("bc" in Table 1). Mean total catches per haul were significantly lower for seines than for trawls, but mean catch rate for seines with mesh sizes ≥ 110 mm was significantly higher than for the three other categories. All target species of seiners, including plaice *Pleuronectes platessa* L. as the main target species, could also be found on the target list of trawlers. The list of target species for trawlers included five species that were not targeted by seines; dab *Limanda limanda* (L.), lemon sole *Microstomus kitt* (Walbaum), Norway lobster, sole *Solea solea* (L.) and turbot *Scophthalmus maximus* (L.).

3.2 Catches

Twelve species were considered (Table 2) of which three had no quota limits in 2016 (dab, lemon sole, witch flounder *Glyptocephalus cynoglossus* (L.)) in the study area, but were directly targeted by some vessels. Nine of these species are subject to MS regulations, but the MCRS of Norway lobster is different to the former MLS and the MS of witch flounder is only legal on a national level in some countries (Table 2). All species were observed in both gear types and mesh categories, but occurrences of herring *Clupea harengus* L., Norway lobster and Norway pout *Trisopterus esmarkii* Nilsson were low in seines (Table 2).

Mean catch rates ranged 0.0–971.2 individuals per hour (Norway lobster in both seine categories and in trawls 90–109 mm, respectively; Table 3). Regarding fish species, catch rates ranged from 0.1 (Norway pout in both seine categories) to 481.1 individuals per hour (plaice in seines ≥ 110 mm, Table 3). Catch rates for plaice and witch flounder were significantly higher in seines and for saithe *Pollachius virens* (L.) and whiting *Merlangius merlangus* (L.) in trawls (Table 4). Catch rate was often significantly affected when Norway lobster or plaice, as main target species of the fisheries, were the targeted species (Table 4). In cases where Norway lobster was targeted, catch rates of Norway lobster and roundfish increased, but catch rates of flatfish decreased. If plaice was targeted, then catch rates of Norway lobster and roundfish decreased, but catch rates of flatfish increased. Mesh size was significant for four species (Norway lobster, saithe, whiting, witch flounder), where catch rates decreased slightly with increasing mesh size for three of them (Table 4). Season was significant for seven species (Table 4), but the differences between the four seasons were species-dependent and no general pattern was found. Water depth was found to be significant for all species and latitude was significant for seven of them (Table 4). Since latitude and water depth were handled as smooth terms, a determination of the direction of impacts has not been possible here. Vessel or trip or both random effects were significant for all species except Norway pout.

Mean values of the MS ratios ranged from 0% (hake *Merluccius merluccius* (L.): all categories except trawls 90–109 mm, Norway lobster: trawls ≥ 110 mm, saithe: all categories except for trawls ≥

110 mm, witch flounder: seines 90–109 mm) to 50% (Norway lobster: seines 90–109 mm and trawls 90–109 mm, plaice: seines ≥ 110 mm, whiting: both seine categories, Table 3) and differences between the gear and mesh categories were small (Table 5). Gear was found to have a significant effect on the MS ratio of whiting (lower for trawls), and mesh size had a negative effect on the ratios of haddock *Melanogrammus aeglefinus* (L.). Season was significant for four species (cod, dab, plaice, whiting) whereby season four was often the decisive season (lower ratios). Target species significantly affected ratios of four species (cod, dab, haddock, Norway lobster), where Norway lobster significantly increased the ratios of cod and haddock. The smooth terms depth and latitude were significant factors for five (cod, haddock, hake, whiting, witch flounder) and one species (Norway lobster), respectively. Random effects were also found to be of high importance; only cod did not show any significant effects of those (Table 5).

4 DISCUSSION

Fishing operation and catch profiles of commercial species for seiners and trawlers fishing in the Skagerrak and the northern Kattegat were compared based on 16 years of Danish observer coverage. This represents a comprehensive data source to evaluate and determine how specialized and flexible the two gears are in terms of target species and catches of fish below MS. The collected data is used to indicate how appropriate the legislative grouping of seines and trawls is and how challenged the two fisheries will be in meeting the objectives of the landing obligation.

Total catches per hour were larger for seiners using mesh sizes ≥ 110 mm than for trawlers. Translating those to catches per swept km^2 based on estimates of hourly swept area by Eigaard et al. (2016b) led to similar or even higher values for trawlers (seines 90–109 mm: 161.4 kg; seines ≥ 110 mm: 274.8 kg; trawls 90–109 mm: 267.1 kg; trawls ≥ 110 mm: 360.0 kg). In other words, seiners are able to fish on a larger area in shorter time, but trawling collects more fish from an area than seining does. Higher flatfish catch rates for seiners than for trawlers and lower engine power with an expected lower fuel consumption and CO_2 emission, as also reported by Thrane (2004), demonstrate that seining is an energy efficient way of catching plaice and other flatfish species. Seiners generally fished in shallower waters than trawlers and are more restricted to flat areas to avoid damage to the seine ropes and the lighter ground gears. As a high proportion of the herding process of seines is made up by visual stimuli (seine ropes and sediment re-suspended by those), seining requires daylight to be operated efficiently. Contrary, trawlers can operate during day and night time, use sweeps which are much shorter than seine ropes and trawls are often equipped with devices like bobbins or use rockhopper ground gear designs to protect the netting from damage by rough bottoms (He & Winger, 2010). This makes trawlers more flexible as they can operate on more diverse fishing grounds, which explains the longer list of target species for trawlers than for seiners. These differences highlight the disparity of seines and trawls. In relation to the landing obligation, this means that seiners are more vulnerable in case quotas or stocks for their few target species (mainly flatfish) are low. Contrary trawlers can shift to another target species and continue fishing more easily.

Very low R^2 values in the ANOVA approach as well as the results of the GAMM approach highlighted the importance of parameters other than gear and mesh size in determining catch rates and the MS ratio. Conditional parameters such as latitude or season and random effects (vessel and/or trip) were found to have significant effects on the catches of most species. This may indicate that it is primarily not the gear or mesh size that is directly responsible for differences in MS ratios or catch rates between the two fishing methods, but more likely the specific conditions in which the gears are used. As these conditions include area and depth as factors of high importance in determining the catch rate and the proportion of fish below MLS or MCRS, differences in the catches are likely between different regions and habitat types. Although this indicates that ecological factors are likely to be underrepresented in current fishery management plans of the EU, adding more detailed area aspects and ecological conditions to future management plans might be problematic due to the diverse and complex structure of marine habitats. The unexpectedly weak effect of mesh size on catch rate and particularly MS ratio has also been observed previously using similar observer collected data. Feekings et al. (2012) were inconclusive about the importance of mesh size on the discard rates of plaice and suggested that the heterogeneity in the sampling across mesh sizes and other factors was likely the cause of this phenomenon. The high importance of vessel and/or trip as random effects in determining catches was also found by several other studies (Feekings et al., 2013; Poos & Rijnsdorp, 2007; Tschernij & Holst, 1999). There may, however, be other influential factors (e.g. selective devices, quota availability) that could affect catch rates or MS ratios. Although the regulations in the study area changed several times, potential effects on catches of seines and trawls were considered to be similar because both belong to the same legislative category (Council Regulation (EC) 850/98). Nevertheless, the quality of the data collected within the observer programmes could be improved by a more precise recording of additional factors like an accurate description of used selective devices. The currently poor recording of the use of selective devices did not allow inclusion of this factor in the analyses, and this may explain why only a weak impact of mesh size was found in the present study. The relatively high number of zero observations in the dataset might be reduced by increasing the sample size within the observer programme. As it could also be possible that conditional factors are linked and interact, effects of gear or mesh size were maybe confounded or masked in the present study. One way to investigate this would be studies that compare catches of seiners and trawlers under more controlled conditions. This means that additional factors such as area, depth or season should be the same for both gears and that same gear configurations (e.g. number of meshes around codend, length of codend extension, selectivity devices) are used or that analyses account for potential differences in those.

Despite the pronounced effects of conditional parameters, significant differences were found in catch rates between seines and trawls for several species. The results indicated that catch rates of flatfish were generally higher for seiners and catch rates for roundfish species were higher for trawlers. Significant differences in MS ratios were only found for whiting, which is not directly targeted. Thus, the results of the present study for fish below MS provide no clear findings to challenge the legislative grouping of seines and trawls into the same category. In the context of the landing-obligation system, the results indicate that both fisheries will be affected as catches of both gears were up to 50% individuals below MCRS, e.g. for the most important target species of both gears (Norway lobster and plaice, respectively).

Future studies that investigate survival of discards in the two fisheries may reach different conclusions if, for example, survival rates are higher for seines than for trawls. Shorter haul durations, shallower fishing grounds and smaller total catches were found in seines than in trawls. Besides the late entry of fish into the net and the corresponding short time within the gear (Herrmann et al., 2016; Noack et al., 2017), these are all factors that a have positive impact on the survivability of discarded fish (van der Reijden et al., 2017). Previous studies on discard survival focused on different types of trawling like beam trawling (Depestele, Desender, Benoît, Polet & Vincx, 2014; Uhlmann et al., 2016; van der Reijden et al., 2017) and otter trawling (Methling, Skov & Madsen, 2017), but no studies have so far investigated discard survival probabilities for Danish seines. Future discard survival studies should include these and compare results to trawl studies. Because temperature, storage and handling time were also found to affect survival (van der Reijden et al., 2017), these factors should be considered in such studies as well.

The minor differences in MS ratios between the gears indicate that if both gears will be grouped together for the foreseeable future, challenges like the handling and storage (Sardà, Coll, Heymans & Stergiou, 2015) or the later sale of this less valuable part of the catch are probably similar for both. To account for the mismatch in the size of caught Norway lobster and MLS (carapace length: 40 mm), the MCRS is reduced to 32 mm carapace length. However, the approach of excluding mesh sizes < 90 mm in the present study in order to compare only similar mesh sizes likely ignored considerable amounts of Norway lobster and fish below MS in trawl catches. The majority of the trawl fleet in the Skagerrak/Kattegat area used mesh sizes below 90 mm until 2005 to fish for their main target Norway lobster, which requires the use of small mesh sizes (Krag, Frandsen & Madsen, 2008). Today they use a mesh size of 90 mm. The smaller fleet of seiners usually uses larger mesh sizes as they do not target Norway lobster. Mesh sizes of 120 mm are normally used to avoid catches of smaller fish. For flatfish-targeting active fisheries (e.g. Danish seining), an obvious way to reduce the number of small individuals in the catch could be an increase in the codend mesh size (Glass, 2000; Krag et al., 2008). As trawlers target different species of fish, but also crustaceans, different options are needed and increases in mesh size could be supported by selective devices (e.g. escape panels or grids) as an option to exclude unwanted fish (Frandsen, Holst & Madsen, 2009; Valentinsson & Ulmestrand, 2008). However, research is still needed to improve their selective properties. The present study reveals trawling to be an opportunistic and flexible fishing method, able to target several different species on a variety of different substrata, whereas seining is specialised on catching primarily flatfish efficiently. Highly specialized fishing gear can be challenged in fast changing biological and management systems. Contrary to trawlers, seiners will not have the opportunity to switch to other fisheries in the case of low market prices or low quotas. Therefore, combining the advantages of trawlers and seiners could be a conceivable approach which is already recognized by the industry as several of the new fishing vessels coming into the fleet are combination vessels capable of both trawling and demersal seining (Scottish seining or fly-shooting). Such combination vessels give the fishers high efficiency in accessing the available fisheries and a high flexibility to continuously optimize the catch composition, as needed under the new landing obligation, to optimize the vessel´s quota capitalization.

Another relevant point in relation to the introduction of the landing obligation is the shift from a landing quota regime to a catch quota management (CQM) regime in order to reduce discards. As fish below MLS or MCRS are of lower value than larger individuals, fishing without discarding would result in lower incomes for the fishers. An analysis of the results of CQM-trials from Denmark concluded, for instance, that earnings of fishers following this system would be less compared to fishers harvesting according to the conventional rules if no compensation would be given to them (Msomphora & Aanesen, 2015). Compensations like extra quota or more days at sea resulted, however, in a higher gross income for fishers following the new system (Msomphora & Aanesen, 2015).

The present study found Danish seining to be an efficient fishing gear for catching flatfish, which is restricted to flat fishing grounds. Trawlers are more flexible in terms of fishing areas and target species and catch roundfish more efficiently. Numbers of fish below MS were similar for seines and trawls, but may have been different if mesh sizes < 90 mm would have been included in the study. Additional factors that are relevant in terms of comparing seines and trawls are the efficiency of selective devices and the survivability of discards as both are likely affected by the differences (gear design, fishing procedure) between both gears.

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Figure 1. Study area and location of fishing operations separated by gear and mesh size category. Danish seines 90–109 mm (black dots as anchor points, n = 80). Danish seines ≥110 mm (white dots as anchor points, n = 205). Demersal otter trawls 90–109 mm (black lines as haul tracks, n = 381). Demersal otter trawls ≥110 mm (white lines as haul tracks, n = 79). Grey shading notes bathymetry of the study area.

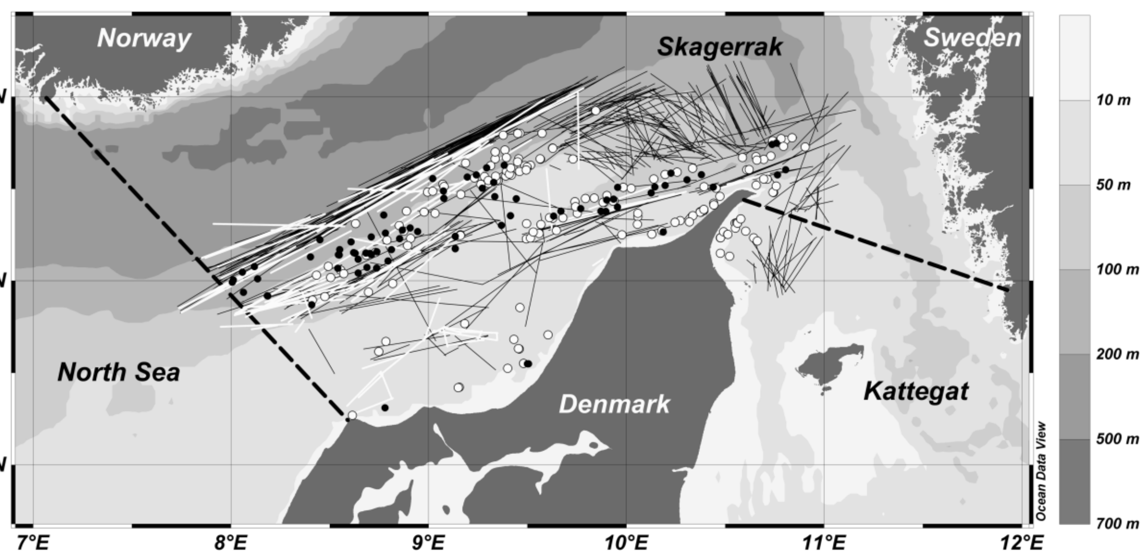

Table 1. General gear comparison using mean values ± standard deviation including df (degrees of freedom) and adjusted R^2 as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$). Target species (according to skipper) describe species targeted by the different gear categories in descending order, number in parenthesis reflects number of hauls targeting this species.

	90–109 mm		≥ 110 mm		df	adj. R^2
	Seine	Trawl	Seine	Trawl		
Years	11	16	14	11	-	-
Vessels (no.)	11	55	22	19	-	-
Engine power (kW)	214.9 ± 90.0 a	404.4 ± 194.1 b	169.6 ± 105.2 a	457.2 ± 265.5 b	741	0.30
Hauls (no.)	80	381	205	79	205	-
Haul duration (min)	172.0 ± 23.9 a	369.7 ± 101.2 b	154.7 ± 35.9 a	356.2 ± 101.6 b	741	0.60
Fishing depth (m)	75.1 ± 39.2 b	109.2 ± 68.1 c	52.4 ± 38.0 a	92.3 ± 67.5 bc	739	0.15
Catch per haul (kg)	464.9 ± 320.1 a	879.9 ± 589.6 b	700.5 ± 772.5 a	1151.4 ± 1527.3 c	741	0.05
Catch per hour (kg)	161.4 ± 111.2 a	146.9 ± 93.8 a	274.8 ± 294.6 b	198.0 ± 261.9 a	741	0.07
Target species (No. of hauls)	Plaice (60) Witch flounder (8) Cod (7) Haddock (5)	Norway lobster (222) Cod (59) Saithe (32) Plaice (26) Witch flounder (16) Sole (13) Haddock (11) Lemon sole (2)	Plaice (103) Cod (68) Haddock (21) Witch flounder (11) Saithe (2)	Plaice (37) Saithe (10) Cod (9) Haddock (9) Witch flounder (4) Lemon sole (3) Norway lobster (3) Dab (2) Turbot (2)		

Table 2. Species overview including information about potential existence of quota in 2016, potentially existing minimum size (cm), total number of observed individuals and occurrence (ratio of hauls with observation to total number of hauls) separated by gear (seine (S) and trawl (T)) and mesh size categories (in mm).

Species	Scientific name	Quota	Minimum size (cm)	Individuals	Occurrence (%)			
					90–109		≥ 110	
					S	T	S	T
Cod	*Gadus morhua* L.	yes	30	151964	98	96	88	91
Dab	*Limanda limanda* (L.)	no	-	174856	81	46	81	67
Haddock	*Melanogrammus aeglefinus* (L.)	yes	27	154929	78	84	53	72
Hake	*Merluccius merluccius* (L.)	yes	30	13215	70	64	30	41
Herring	*Clupea harengus* L.	yes	18	6399	9	37	6	22
Lemon sole	*Microstomus kitt* (Walbaum)	no	-	24794	91	67	64	62
Norway lobster	*Nephrops norvegicus* (L.)	yes	total: 13, carapace: 4[1]	1910743	1	72	1	14
Norway pout	*Trisopterus esmarkii* (Nilsson)	yes	-	13425	4	30	6	9
Plaice	*Pleuronectes platessa* L.	yes	27	498873	96	85	99	82
Saithe	*Pollachius virens* (L.)	yes	30	54705	41	60	20	56
Whiting	*Merlangius merlangus* (L.)	yes	23	46714	35	70	21	48
Witch flounder	*Glyptocephalus cynoglossus* (L.)	no	-[2]	65207	79	80	47	52

[1] new: total length: 10.5; tail length: 5.9; carapace length: 3.2

[2] no Minimum Landing Size (MLS) on EU level, but local MLS of 28 cm in Germany, Denmark, Scotland, Sweden and parts of England

Table 3. Catch rates (ind./h) and minimum size (MS) ratios (individuals below minimum landing size (MLS) or minimum conservation reference size (MCRS)/total no. of individuals) ± SD separated by gear and mesh size.

Species	Catch rate				MS ratio			
	90–109 mm		≥ 110 mm		90–109 mm		≥ 110 mm	
	Seine	Trawl	Seine	Trawl	Seine	Trawl	Seine	Trawl
Cod	47.7 ± 48.3	38.3 ± 51.9	54.2 ± 109.2	47.2 ± 64.4	0.2 ± 0.2	0.4 ± 0.3	0.3 ± 0.3	0.1 ± 0.2
Dab	38.3 ± 75.8	51.8 ± 127.2	74.6 ± 178.2	40.9 ± 142.1	–	–	–	–
Haddock	38.3 ± 47.5	40.9 ± 82.8	33.1 ± 76.8	62.2 ± 115.2	0.1 ± 0.2	0.4 ± 0.4	0.2 ± 0.3	0.1 ± 0.2
Hake	2.6 ± 5.6	5.0 ± 10.2	1.9 ± 8.0	1.1 ± 2.2	0.0 ± 0.0	0.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.1
Herring	0.2 ± 0.7	2.5 ± 8.0	0.3 ± 2.1	1.0 ± 4.1	0.2 ± 0.4	0.1 ± 0.3	0.4 ± 0.4	0.2 ± 0.3
Lemon sole	14.6 ± 14.5	6.4 ± 21.1	5.1 ± 12.3	8.2 ± 14.6	–	–	–	–
Norway lobster	0.0 ± 0.2	971.2 ± 1952.0	0.0 ± 0.0	30.2 ± 153.5	0.5 ± 0.0	0.5 ± 0.3	0.0 ± 0.0	0.3 ± 0.3
Norway pout	0.1 ± 0.8	5.3 ± 27.1	0.1 ± 0.8	0.5 ± 2.7	–	–	–	–
Plaice	280.1 ± 689.7	60.3 ± 148.4	481.1 ± 849.7	146.1 ± 194.1	0.2 ± 0.2	0.4 ± 0.4	0.5 ± 0.4	0.3 ± 0.4
Saithe	2.7 ± 14.0	15.3 ± 49.1	3.9 ± 44.6	22.5 ± 82.8	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.2	0.1 ± 0.2
Whiting	0.9 ± 2.2	20.8 ± 37.1	1.1 ± 4.3	4.1 ± 9.1	0.5 ± 0.4	0.4 ± 0.3	0.5 ± 0.4	0.1 ± 0.2
Witch flounder	33.2 ± 63.1	17.1 ± 30.7	17.4 ± 45.2	6.7 ± 11.5	0.0 ± 0.0	0.2 ± 0.3	0.1 ± 0.2	0.0 ± 0.1

Table 4. Model results for catch rates (log-transformed) including significance levels. Smooth terms and random terms given as estimated degrees of freedom (edf).

Species	η	Predictors								Explained deviance (%)
		Categorical term estimates				Smooth term (edf)		Random term (edf)		
		Gear (trawl)	Mesh	Season	Target	Depth	Latitude	Vessel	Trip	
Cod	2.3***				Plaice (–0.5)***	2.8***	7.6***	34.2***	128.8***	72.1
Dab	0.3*				Dab (5.3)**	2.9***	4.4***	36.1*	112.7**	88.9
Haddock	0.6***			4 (0.5) *		3.0***		38.3**	133.2**	87.0
Hake	–3.1***			2 (1.5)** 3 (1.9)*** 4 (1.8)***	Haddock (–0.6)** Norway lobster (1.1)***	1.0***	9.0**	58.7	128.9*	88.7
Herring	–1.9***			3 (-1.6) *	Plaice (–2.7)***	2.4**		25.7	83.1*	91.3
Lemon sole	0.1			2 (0.6) **	Dab (3.2)* Norway lobster (–1.4)*** Saithe (–1.3)*	2.8***	4.8**	21.9	93.5***	77.8
Norway lobster	14.7***		–0.1***		Haddock (–1.8)** Norway lobster (2.2)*** Plaice (–3.9)***	2.5***		50.3**	85.2**	97.7
Norway pout	–4.9***				Norway lobster (1.5)***	3.0***	7.8***	49.4	63.2	89.6
Plaice	2.9***	–0.9***		4 (-0.6)***	Dab (3.7)*** Norway lobster (–0.7)*** Plaice (0.5)***	2.8***		34.3	127.3*	92.3
Saithe	–5.9***	1.1**	0.0*	2 (1.5)*** 3 (1.3)*** 4 (1.3)***		2.8***	1.4*	0.0	123.5***	92.6
Whiting	5.0**	1.2*	-0.0*	2 (-2.0)*** 3 (-1.3)*** 4 (-0.8) ***	Plaice (–1.7)***	2.7***		36.6	128.0*	89.8
Witch flounder	4.5***	–1.3***	-0.0***		Witch flounder (0.5)*	2.9***	2.1*	13.6	111.3***	85.3

Significance levels: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; η = intercept (gear: Danish seine, season: 1, target: cod)

Table 5. Model results for minimum size ratio (individuals below minimum landing size or minimum conservation reference size/total no. of individuals, logit-transformed) including significance levels. Smooth terms and random terms given as estimated degrees of freedom (edf).

Species	η	Predictors								Explained deviance (%)
		Categorical term estimates				Smooth term (edf)		Random term (edf)		
		Gear (trawl)	Mesh	Season	Target	Depth	Latitude	Vessel	Trip	
Cod	–1.6***			4 (–1.1)***	Norway lobster (0.6)*	3.0***		80.3	117.2	72.0
Haddock	2.1		–0.0**		Norway lobster (1.2)*** Saithe (1.4)**	2.2***		24.0***	12.3	45.8
Hake	–5.3					2.0***		61.2	74.0*	89.9
Norway lobster	–0.7*				Haddock (–1.3)* Norway lobster (–1.2)*** Saithe (–0.9)* Witch flounder (–1.8)***		1.0**	35.7***	32.6	64.7
Plaice	–1.9***			4 (–1.2)**				80.6*	116.9**	78.6
Whiting	–1.0**	–1.0*		2 (1.0)** 4 (–1.1)**		1.2***		21.9	69.4*	67.7
Witch flounder	–3.9**					1.0**		69.1	113.1***	89.4

Significance levels: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, η = intercept (gear: Danish seine, season: 1, target: cod)

Supplementary material

Table S1. Quota in Skagerrak-Kattegat area (Ministry of Environment and Food of Denmark, Danish Agrifish Agency) and total annual landings (t) of commercial species in Denmark for 2016.

Species	Quota in Kattegat/Skagerrak (t)	Total annual landings in Denmark	
		Bottom trawls	Danish seines
Cod	Kattegat: 233; Skagerrak: 3747	15584	941
Dab	-	779	294
Haddock	3400	1233	334
Hake	1334	1739	109
Herring	16538	664	0
Lemon sole	-	1122	35
Norway lobster	8513	4088	0
Norway pout	99907*	19627	0
Plaice	Kattegat: 2089; Skagerrak: 9234	15356	4392
Saithe	4091*	3238	7
Whiting	926	309	13
Witch flounder	-	1239	164

*incl. North Sea

Table S2. Catch rate (individuals/h) as mean value ± standard deviation including df (degrees of freedom) and adjusted R^2 as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	Catch rate				df	adj. R^2
	90 - 109 mm		≥ 110 mm			
	Seine	Trawl	Seine	Trawl		
Cod	47.7 ± 48.3 a	38.3 ± 51.9 a	54.2 ± 109.2 a	47.2 ± 64.4 a	741	0.00
Dab	38.3 ± 75.8 a	51.8 ± 127.2 a	74.6 ± 178.2 a	40.9 ± 142.1 a	741	0.00
Haddock	38.3 ± 47.5 ab	40.9 ± 82.8 ab	33.1 ± 76.8 a	62.2 ± 115.2 b	741	0.01
Hake	2.6 ± 5.6 ab	5.0 ± 10.2 b	1.9 ± 8.0 a	1.1 ± 2.2 a	741	0.03
Herring	0.2 ± 0.7 a	2.5 ± 8.0 b	0.3 ± 2.1 a	1.0 ± 4.1 ab	741	0.03
Lemon sole	14.6 ± 14.5 b	6.4 ± 21.1 a	5.1 ± 12.3 a	8.2 ± 14.6 ab	741	0.02
Norway lobster	0.0 ± 0.2 a	971.2 ± 1952.0 b	0.0 ± 0.0 a	30.2 ± 153.5 a	741	0.10
Norway pout	0.1 ± 0.8 ab	5.3 ± 27.1 a	0.1 ± 0.8 b	0.5 ± 2.7 ab	741	0.01
Plaice	280.1 ± 689.7 b	60.3 ± 148.4 a	481.1 ± 849.7 c	146.1 ± 194.1 ab	741	0.11
Saithe	2.7 ± 14.0 ab	15.3 ± 49.1 b	3.9 ± 44.6 a	22.5 ± 82.8 b	741	0.01
Whiting	0.9 ± 2.2 a	20.8 ± 37.1 b	1.1 ± 4.3 a	4.1 ± 9.1 a	741	0.11
Witch flounder	33.2 ± 63.1 b	17.1 ± 30.7 a	17.4 ± 45.2 a	6.7 ± 11.5 a	741	0.02

Table S3. Minimum size (MS) ratio (individuals below minimum landing size (MLS) or minimum conservation reference size (MCRS)/total no. of individuals) ± standard deviation including df (degrees of freedom) and adjusted R^2 as measure of explained deviance. Mean values that are not sharing a letter (a, b, c) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	MS ratio				df	adj. R^2
	90 - 109 mm		≥ 110 m			
	Seine	Trawl	Seine	Trawl		
Cod	0.2 ± 0.2 ab	0.4 ± 0.3 c	0.3 ± 0.3 b	0.1 ± 0.2 a	693	0.08
Haddock	0.1 ± 0.2 a	0.4 ± 0.4 b	0.2 ± 0.3 a	0.1 ± 0.2 a	543	0.17
Hake	0.0 ± 0.0 a	0.2 ± 0.3 b	0.0 ± 0.0 a	0.0 ± 0.1 a	388	0.11
Herring	0.2 ± 0.4 a	0.1 ± 0.3 a	0.4 ± 0.4 a	0.2 ± 0.3 a	173	0.02
Norway lobster	0.5 ± 0.0 ab	0.5 ± 0.3 b	0.0 ± 0.0 a	0.3 ± 0.3 a	284	0.04
Plaice	0.2 ± 0.2 a	0.4 ± 0.4 bc	0.5 ± 0.4 c	0.3 ± 0.4 ab	664	0.05
Saithe	0.0 ± 0.1 a	0.0 ± 0.1 a	0.0 ± 0.2 a	0.1 ± 0.2 a	345	0.00
Whiting	0.5 ± 0.4 b	0.4 ± 0.3 b	0.5 ± 0.4 b	0.1 ± 0.2 a	372	0.06
Witch flounder	0.0 ± 0.0 a	0.2 ± 0.3 b	0.1 ± 0.2 a	0.0 ± 0.1 a	501	0.14